

The first photometric analysis of the overcontact binary MQ UMa with an additional component

X. Zhou^{1,2,3}, S.-B. Qian^{1,2,3}, W.-P. Liao^{1,2}, E.-G. Zhao^{1,2,3}, J.-J. Wang^{1,2,3}, L.-Q. Jiang^{1,2,3}

ABSTRACT

The first $V R_c I_c$ bands light curves of MQ UMa are presented and analyzed using the Wilson-Devinney (W-D) program. It is discovered that MQ UMa is an A-subtype contact binary with a high fill-out ($f=82\%$) and a low mass ratio ($q = 0.195$), which indicates that it is in the late evolutionary stage of late-type tidal-locked binary stars. The mass of the primary and secondary stars are estimated and the evolutionary status of the two components are placed in the H-R diagram. The W-D solutions also indicates that MQ UMa may be a triple system with an F5V type additional component. A sample of sixteen high fill-out, low mass ratio overcontact binaries are collected and their possible evolution scenarios are discussed. Using the five times of light minimum recently observed together with those collected from literatures, the authors find that the observed-calculate ($O-C'$) curve exhibits a cyclic period variation. The cyclic period change also reveals the presence of a tertiary component, which may play an important role in the formation and evolution of this binary system by drawing angular momentum from the central system.

Subject headings: binaries : close – binaries : eclipsing – stars: evolution – stars: individual (MQ UMa)

1. Introduction

W UMa type binaries are cool short-period (usually less than 1 day) binary systems with both components filling their critical Roche lobes and sharing a common convective envelope

¹Yunnan Observatories, Chinese Academy of Sciences (CAS), P. O. Box 110, 650216 Kunming, China; zhouxiaophy@ynao.ac.cn

²Key Laboratory of the Structure and Evolution of Celestial Objects, Chinese Academy of Sciences, P. O. Box 110, 650216 Kunming, China

³University of the Chinese Academy of Science, Yuquan Road 19#, Sijingshang Block, 100049 Beijing, China

during their main sequence evolutionary stage. The formation and evolution of W UMa type binary systems are still unsolved problems in astrophysics. The most popular evolutionary scenario is that they are formed from initially detached systems via angular momentum loss (AML) by means of magnetic stellar wind (Vilhu 1982; Eggen & Iben 1989). Model calculations suggest that these binary stars will ultimately coalesce into single stars which may be progenitors of the poorly understood blue stragglers and FK Com stars (Stępień 2006, 2011). It has been widely accepted that the eruption of V1309 Sco was the result of a cool short-period binary merging. In this paper, we focus on the high fill-out, low mass ratio overcontact binaries which are at the late evolutionary stages of the contact configuration. Photometric analysis and orbital period studies of them will provide important information for the evolution and coalescence scenario of these binary systems.

MQ UMa, also named GSC 3015 0374, is a typical W UMa type contact binary. It was first discovered by CCD observations from large-scale automatic sky surveys in 1999 (Kazarovets et al. 2005). Since then, several times of light minimum have been published, and it is included in the Tycho-2 Catalogue and 2MASS All Sky Catalogue. The Tycho-2 Catalogue gives the magnitude of MQ UMa, which are 11.77 (0.09) mag in B band and 11.22 (0.09) mag in V band. The 2MASS All Sky Catalogue gives the magnitude of MQ UMa in J , H and K band filters, which are 10.616 (0.026) mag in J band, 10.402 (0.028) mag in H band and 10.387 (0.018) mag in K band. However, there is neither light curve (LC) photometric solution nor spectroscopic information about this target.

2. The CCD photometric light curves and times of light minimum

The V R_c and I_c bands CCD observations of MQ UMa were carried out in three nights on January 19, March 7 and April 26, 2014 with an Andor DW436 1K CCD camera attached to the 85cm reflecting telescope at Xinglong Observation Base. The coordinates of the variable star, the comparison star and the check star were listed in Table 1. During the observation, the broad band, Johnson-Cousins V R_c I_c filters were used. The integration time were 60s for V band, 40s for R_c band, and 30s for I_c band, respectively. PHOT (measure magnitudes for a list of stars) of the aperture photometry package in the IRAF¹ was used to reduce the observed images. The average observational errors were 0.002 mag for V band, 0.003 mag for R_c band and 0.003 mag for I_c band, respectively. The light curves of those observations were displayed in Fig. 1.

¹The Image Reduction and Analysis Facility is hosted by the National Optical Astronomy Observatories in Tucson, Arizona at URL iraf.noao.edu.

Table 1: Coordinates of MQ UMa, the comparison, and the check stars.

Targets	name	α_{2000}	δ_{2000}
Variable	MQ UMa	$11^h21^m41^s.1$	$+43^\circ36'52''.8$
The comparison	GSC 3015 0367	$11^h21^m19^s.2$	$+43^\circ38'09''.9$
The check	GSC 3015 0408	$11^h21^m19^s.2$	$+43^\circ31'51''.4$

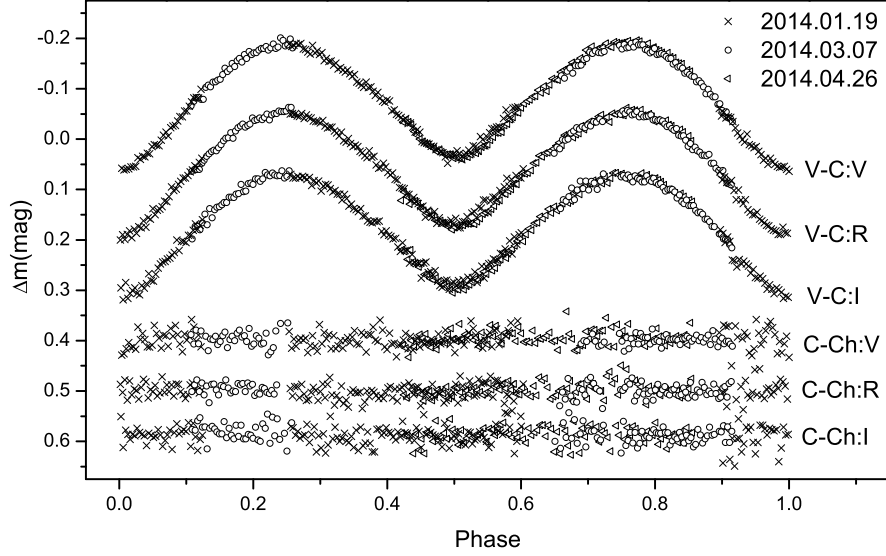


Fig. 1.— CCD photometric light curves in V , R_c and I_c bands. The magnitude difference between the comparison and the check stars are presented. The standard deviations of the comparison-check observations are 0.015 mag for V band, 0.015 mag for R_c band and 0.017 mag for I_c band. Crosses, open circles and triangles correspond to the data observed on January 19, March 7 and April 26, respectively.

We also got three times of light minimum on January 19 and April 26, 2014 while doing light curve observations. After that, one time of light minimum was obtained on January 3, 2015 using the 60cm reflecting telescope in Yunnan Observatories (YNOs), and another TOM was obtained on January 12, 2015 using the 1m reflecting telescope in YNOs. Basing on the least-square parabolic fitting method, five new CCD times of light minimum were determined and listed in Table 2.

Table 2: New CCD times of light minimum for MQ UMa.

JD (Hel.)	Error (days)	Min.	Filter	Method	Telescopes
2456677.1653	± 0.0004	I	VR_cI_c	CCD	85cm
2456677.4031	± 0.0005	II	VR_cI_c	CCD	85cm
2456774.0451	± 0.0003	II	VR_cI_c	CCD	85cm
2457026.3616	± 0.0006	II	VR_cI_c	CCD	1m
2457035.4084	± 0.0004	II	I_c	CCD	60cm

Notes. 60cm and 1m denote to the 60cm and 1m reflecting telescope in Yunnan Observatories, and 85cm denotes to the 85cm reflecting telescope in Xinglong Observation base.

3. Orbital period change of MQ UMa

The study of orbital period change is a very important part for contact binary stars. However, the period change investigation of MQ UMa has been neglected since it was discovered. During the present work, all available times of light minimum are collected and listed in Table 3. Using the following linear ephemeris,

$$Min.I(HJD) = 2451312.851 + 0^d.476066 \times E, \quad (1)$$

the $O - C$ (observational times of light minimum-calculational times of light minimum) values are calculated and listed in the fourth column of Table 3 and plotted in the upper panel of Fig 2. Minimum times with the same epoch have been averaged, and only the mean values are listed in Table 3. The general $O - C$ trend of MQ UMa shown in the upper panel of Fig. 2 indicates a cyclic change in its orbital period. Based on the least-square method, a sinusoidal term is added to the linear ephemeris of Equation (2). The new ephemeris is

$$Min.I = 2451312.85732(\pm 0.00029) + 0.47606620(\pm 0.00000003) \times E \\ + 0.005646(\pm 0.000135) \sin[0.^{\circ}03438 \times E + 264.^{\circ}293(\pm 1.^{\circ}356)] \quad (2)$$

The sinusoidal term reveals a cyclic change with a period of 13.6 years and an amplitude of 0.0056 days. The residuals from Equation (2) are displayed in the lowest panel of Fig. 2.

It has to be mentioned that the data point at $E = 0$ seriously affect the $O - C$ fitting since there is no other time of light minimum between data point at $E = 0$ and $E = 6049$. Thus we check the first data carefully. Although the data point at $E = 0$ did not give its observational error, it was observed by CCD camera. We believe that it has a high time precision as other CCD data. So we add it to the $O - C$ fitting and give the results as above. The cyclic period change in Equation (2) may be caused by the light travel time effect (LTTE) of the third component. Actually, we can only ensure the existence of a

Table 3: $(O - C)$ values of light minima for MQ UMa.

JD (Hel.) (2400000+)	Min	Epoch	$(O - C)$	Error	Method	Reference
51312.8513	I	0	0.0003	—	CCD	1
54192.5885	I	6049	0.0143	0.0008	CCD	2
54499.6476	I	6694	0.0108	0.0030	CCD	3
54518.9277	II	6734.5	0.0102	0.0005	CCD	4
54912.3940	I	7561	0.0080	0.0001	CCD	5
54931.4375	I	7601	0.0088	0.0007	CCD	6
55259.4448	I	8290	0.0066	0.0003	CCD	7
55289.4355	I	8353	0.0052	0.0003	CCD	7
55311.5753	II	8399.5	0.0079	0.0025	CCD	8
55625.2975	II	9058.5	0.0027	0.0010	CCD	9
55644.5823	I	9099	0.0068	0.0003	CCD	10
55660.5289	II	9132.5	0.0052	0.0034	CCD	11
55669.5757	II	9151.5	0.0067	0.0004	CCD	10
55877.6101	II	9588.5	0.0003	0.0005	CCD	9
55937.8357	I	9715	0.0035	0.0004	CCD	12
56003.5322	I	9853	0.0029	0.0020	CCD	9
56003.5325	I	9853	0.0032	0.0003	CCD	9
56011.6263	I	9870	0.0039	0.0004	CCD	13
56677.1653	I	11268	0.0026	0.0004	CCD	14
56677.4031	II	11268.5	0.0023	0.0004	CCD	14
56774.0451	II	11471.5	0.0030	0.0003	CCD	14
57026.3616	II	12001.5	0.0042	0.0006	CCD	14
57035.4084	II	12020.5	0.0057	0.0004	CCD	14

Reference: (1) Kazarovets et al. (2005); (2) Hubscher et al. (2009); (3) Brát et al. (2008); (4) Nelson (2009); (5) Brat et al. (2009); (6) Hubscher et al. (2010); (7) Brat et al. (2011); (8) Hubscher & Monninger (2011); (9) Hoňková et al. (2013); (10) Hubscher & Lehmann (2013); (11) Hubscher et al. (2012); (12) Nelson (2013); (13) Hubscher (2013); (14) present work;

tertiary component. The exact orbit period of the third body can not be determined for the absence of data point between $E = 0$ and $E = 6049$. In the present work, we just estimate a typical period which gives a very nice fitting results in Fig. 2. In order to verify the periodic variations presented here, more determinations of light minima are required in the future.

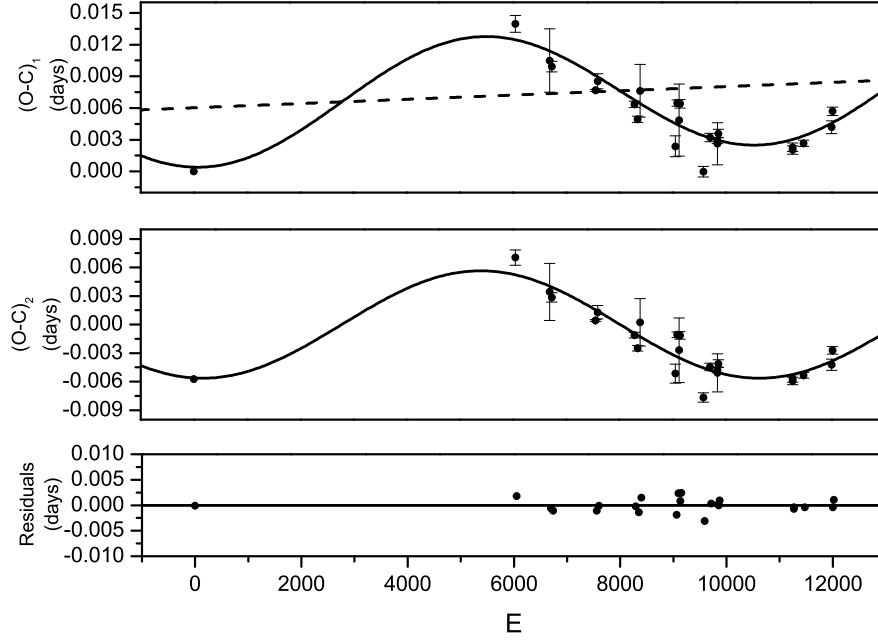


Fig. 2.— The $(O - C)_1$ values of MQ UMa from the linear ephemeris of Equation (1) is presented in the upper panel. The solid line in the panel refers to the combination of a new linear ephemeris and a cyclic variation. The dash line represents the new linear ephemeris. In the middle part of Fig. 2, $(O - C)_2$ values calculated from the new linear ephemeris in Equation (2) are displayed. The solid line refers to a theoretical light travel time effect (LTTE) orbit of the tertiary component in the system. The residuals from the whole effect are displayed in the lowest panel.

4. Photometric solutions of MQ UMa

MQ UMa is a newly determined binary system, and neither light curve photometric solution nor spectroscopic observation has been published since it was discovered in 1999 (Kazarovets et al. 2005). As shown in Fig. 1, the light curve variations in three colors are continuous and have very small magnitude differences between the depth of the primary and secondary minima. It means that MQ UMa is a typical EW-type contact binary. In Fig.1, the light curve data have been shifted vertically which will make no difference to the results of W-D program as differential photometry method is used. The phases are calculated with

the following linear ephemeris:

$$Min.I(HJD) = 2456677.1653(4) + 0^d.476058 \times E. \quad (3)$$

To understand its geometrical structure and evolutionary state, the V R_c and I_c light curves shown in Fig. 1 are analyzed using the W-D program of 2013 version (Wilson & Devinney 1971; Wilson 1979, 1990; Van Hamme & Wilson 2007; Wilson 2008; Wilson et al. 2010; Wilson 2012). The number of observational data points used in W-D program are 377 in V band, 380 in R_c band, 375 in I_c band, respectively. According to the Tycho-2 Catalogue measurements, the color index of $B - V = 0.55$, which corresponds to a spectral type of F9, but the 2MASS All Sky Catalogue gives the color index of $J - H = 0.214$, corresponding to a spectral type of F4 (Cox 2000). Thus the spectral type of MQ UMa ranges from F9 to F4, which means the effective temperature of the primary star ranges from 6095K to 6670K (Cox 2000). Meanwhile, we also use the following period - color relation derived by Deb et al. (2011) to estimate the effective temperature of the primary star.

$$J - K = (0.11 \pm 0.01) \times P^{-1.19 \pm 0.08} \quad (4)$$

The equation is derived from a total sample of 141 contact binaries, whose spectral type ranges from A2V to K5V, and has a period from 0.2211 days to 1.1318 days. The sample has covered nearly all kinds of W UMa type contact binaries which means it is appropriate to MQ UMa. The period of MQ UMa is 0.476058 days, so the color index of $J - K$ calculated by Equation (4) is $0.266 (\pm 0.042)$, which corresponds to spectral type of F5 to F7. Because of the advantage of $J - K$ color is not affected by interstellar extinction and uncertain reddening corrections as compared to $B - V$ color, the period-color relation using the infrared color $J - K$ will be much more accurate. According to the temperature estimated by the two methods, the authors argue that MQ UMa is a late-F type W UMa contact binary system and adopt F7V as the spectral type of the primary star.

During the W-D processing, the effective temperature of star 1 is chosen as $T_1 = 6352K$ according to the spectral type determined. Convective outer envelopes for both components are assumed. The bolometric albedo $A_1 = A_2 = 0.5$ (Ruciński 1969) and the values of the gravity-darkening coefficients $g_1 = g_2 = 0.32$ (Lucy 1967) are used. To account for the limb darkening in detail, logarithmic functions are used. The corresponding bolometric and passband-specific limb-darkening coefficients are chosen from Van Hamme (1993)'s table. During the calculating, it is find that the solution converges at mode 3, and the adjustable parameters are: the mass ratio q (M_2/M_1); the orbital inclination i ; the mean temperature of star 2 (T_2); the monochromatic luminosity of star 1 (L_{1V} , L_{1R} and L_{1I}); the dimensionless potential of star 1 ($\Omega_1 = \Omega_2$ in mode 3 for overcontact configuration); and the third light (l_3). Since there is no radial velocity curves of MQ UMa, a q -search method is used to determine

the initial mass ratio at first. Solutions with mass ratio from 0.1 to 8 are investigated, and the relation between the resulting sum of weighted square deviations Σ and q is plotted in Fig. 3. The minimum values are found at $q = 0.2$, which indicates that MQ UMa is an A-subtype contact binary. Then $q = 0.2$ is set as the initial value and considered as an adjustable parameter. The final photometric solutions are listed in Table 4 and the theoretical light curves (with l_3) are displayed in Fig. 4. The contact configuration of MQ UMa is displayed in Fig. 5.

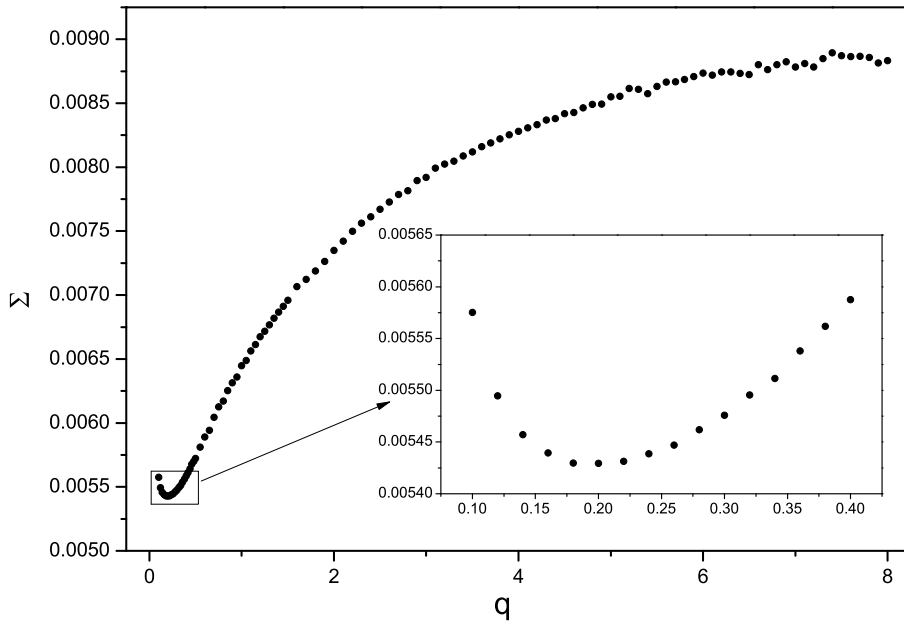


Fig. 3.— Relation between Σ and q for MQ UMa. Σ is the resulting sum of weighted square deviations. It is shown that the minimum is at $q = 0.20$.

To make the photometric solutions of MQ UMa more convinced, we also do q -search of MQ UMa by giving the effective temperature of the primary star at $T_1 = 6100\text{K}$, $T_1 = 6300\text{K}$, $T_1 = 6500\text{K}$, $T_1 = 6700\text{K}$, respectively. As shown in Fig. 6, although the effective temperature of the primary star ranges from 6100K to 6700K, the shape of q -search curves do not have any significant changes. All of the q -search results get the best fitting mass ratio at $q = 0.20 (\pm 0.02)$. The convergent photometric solutions (with l_3) are listed in Table 5. As shown in the table, although there is some uncertainty of T_1 estimation (6100K to 6700K), the solutions give nearly consistent results, which means the W-D program can tolerate the uncertainty of the primary star's temperature estimated by us. Therefore, the solution of $T_1 = 6352\text{K}$ is adoptable and we will take the photometric solutions of $T_1 = 6352\text{K}$ as the final

Table 4: Photometric solutions of MQ UMa

Parameters	Values without l_3	Values with l_3
g_1	0.32(fixed)	0.32(fixed)
g_2	0.32(fixed)	0.32(fixed)
A_1	0.50(fixed)	0.50(fixed)
A_2	0.50(fixed)	0.50(fixed)
q (M_2/M_1)	0.211(± 0.006)	0.195(± 0.008)
$T_1(K)$	6352(fixed)	6352(fixed)
$i(^{\circ})$	60.70(± 0.20)	65.58(± 0.69)
Ω_{in}	2.259129	2.622506
Ω_{out}	2.125046	2.393652
$\Omega_1 = \Omega_2$	2.203736(± 0.001206)	2.117244(± 0.021541)
$T_2(K)$	6116(± 12)	6224(± 25)
$L_1/(L_1 + L_2)$ (V)	0.8211(± 0.0009)	0.8089(± 0.0065)
$L_1/(L_1 + L_2)$ (R)	0.8172(± 0.0009)	0.8068(± 0.0064)
$L_1/(L_1 + L_2)$ (I)	0.8138(± 0.0009)	0.8050(± 0.0065)
$L_1/(L_1 + L_2 + L_3)$ (V)		0.5970(± 0.0102)
$L_1/(L_1 + L_2 + L_3)$ (R)		0.6057(± 0.0099)
$L_1/(L_1 + L_2 + L_3)$ (I)		0.6103(± 0.0100)
$L_3/(L_1 + L_2 + L_3)$ (V)		0.2620(± 0.0068)
$L_3/(L_1 + L_2 + L_3)$ (R)		0.2492(± 0.0064)
$L_3/(L_1 + L_2 + L_3)$ (I)		0.2419(± 0.0064)
$r_1(pole)$	0.4963(± 0.0023)	0.5150(± 0.0038)
$r_1(side)$	0.5436(± 0.0031)	0.5710(± 0.0055)
$r_1(back)$	0.5707(± 0.0030)	0.6022(± 0.0057)
$r_2(pole)$	0.2510(± 0.0115)	0.2585(± 0.0201)
$r_2(side)$	0.2633(± 0.0142)	0.2735(± 0.0257)
$r_2(back)$	0.3114(± 0.0330)	0.3510(± 0.1020)
f	41.3 %(± 0.9 %)	82 %(± 17 %)
$\Sigma\omega(O - C)^2$	0.005077	0.004314

results of MQ UMa hereafter.

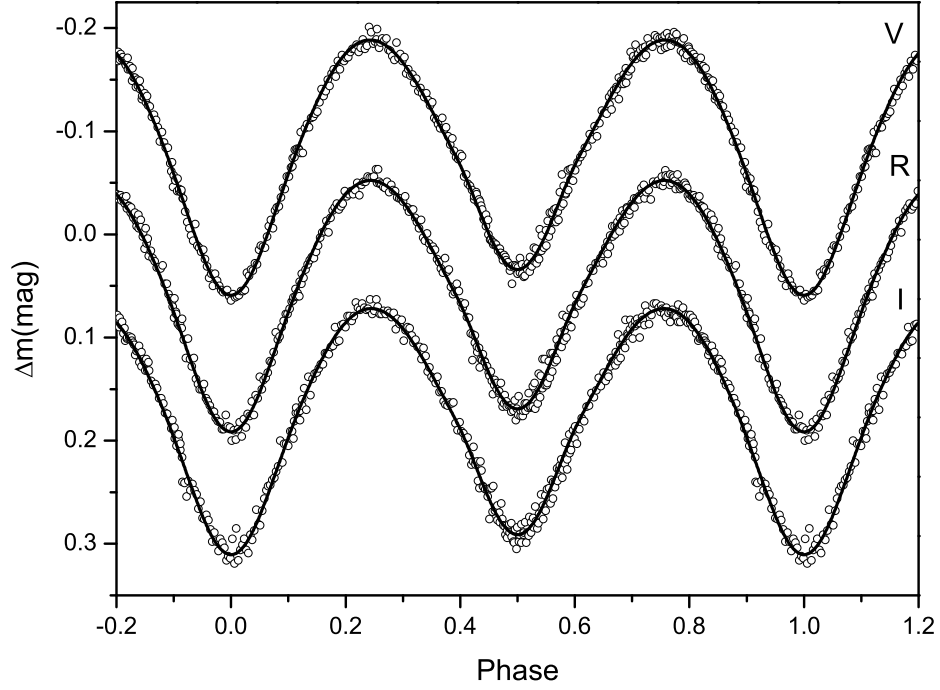


Fig. 4.— Observed (open circles) and theoretical (solid lines) light curves in the VR_c and I_c bands for MQ UMa. The standard deviation of the fitting residuals is 0.006 mag for V band, 0.007 mag for R_c band and 0.008 mag for I_c band, respectively.

Table 5: Photometric solutions of MQ UMa for different effective temperature

Parameters	Values	Values	Values	Values	Values
$T_1(K)$	6700(fixed)	6500(fixed)	6300(fixed)	6100(fixed)	6352(fixed)
$q (M_2/M_1)$	0.202(± 0.005)	0.212(± 0.004)	0.216(± 0.007)	0.208(± 0.005)	0.195(± 0.008)
$i(^{\circ})$	63.09(± 0.66)	61.10(± 0.58)	61.33(± 0.60)	61.24(± 0.60)	65.58(± 0.69)
$\Omega_1 = \Omega_2$	2.158458(± 0.015663)	2.202068(± 0.013527)	2.209652(± 0.018830)	2.193309(± 0.014472)	2.117244(± 0.021541)
$T_2(K)$	6496(± 19)	6270(± 18)	6085(± 16)	5898(± 16)	6224(± 25)
$\Delta T(K)$	204	230	215	202	128
T_2/T_1	0.970(± 0.003)	0.965(± 0.003)	0.966(± 0.003)	0.967(± 0.003)	0.980(± 0.004)
$\Sigma \omega(O - C)^2$	0.004314	0.004317	0.004317	0.004321	0.004314

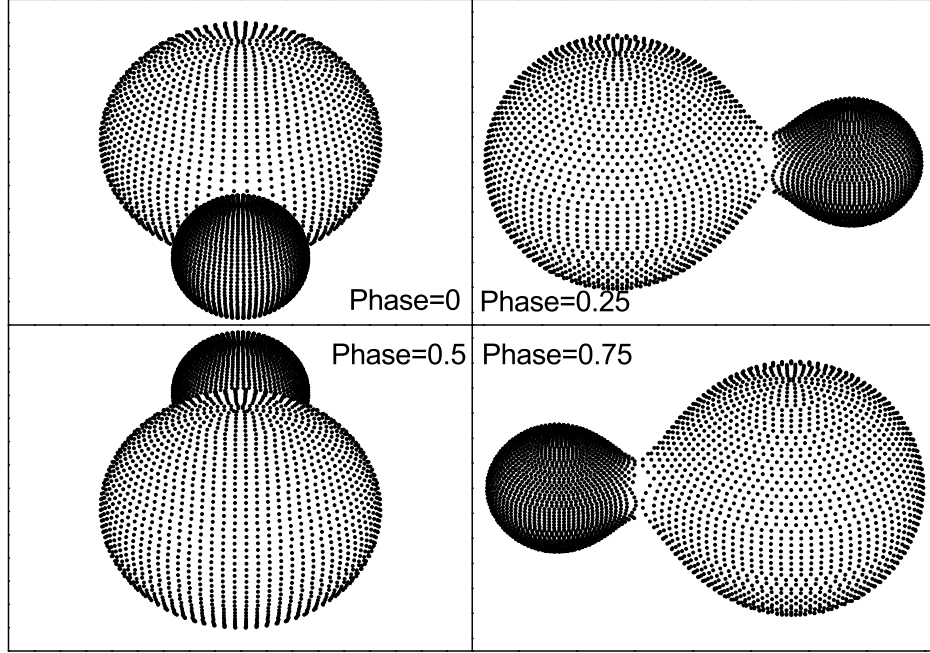


Fig. 5.— Contact configurations of MQ UMa at phase 0.0, 0.25, 0.5, 0.75,

5. Discussions and Conclusions

Light curve solutions indicate that MQ UMa is an A-subtype overcontact binary system with a contact degree of $f = 82\%$. The two components have nearly the same surface temperature ($\Delta T = 128K$) in spite of their quite different masses and radii, which indicates that the system is under thermal contact. The obtained mass ratio is $q = 0.195$. We assume that the mass of the primary component is $M_1 = 1.33M_\odot$ (Cox 2000) according to its spectral type (F7V), then the mass of the secondary is estimated to be $M_2 = 0.28M_\odot$. The evolutionary status of the primary and the secondary stars are plotted in the H-R diagram as shown in Fig. 7. The evolutionary status of the primary star places it in the middle between the Zero Age Main Sequence (ZAMS) and the Terminal Age Main Sequence (TAMS) lines of the H-R diagram. The secondary component is evidently more evolved than the primary star, and it is clearly overluminous and have higher effective temperature for its present mass.

During the photometric processing, the third light (l_3) is also included as an adjustable

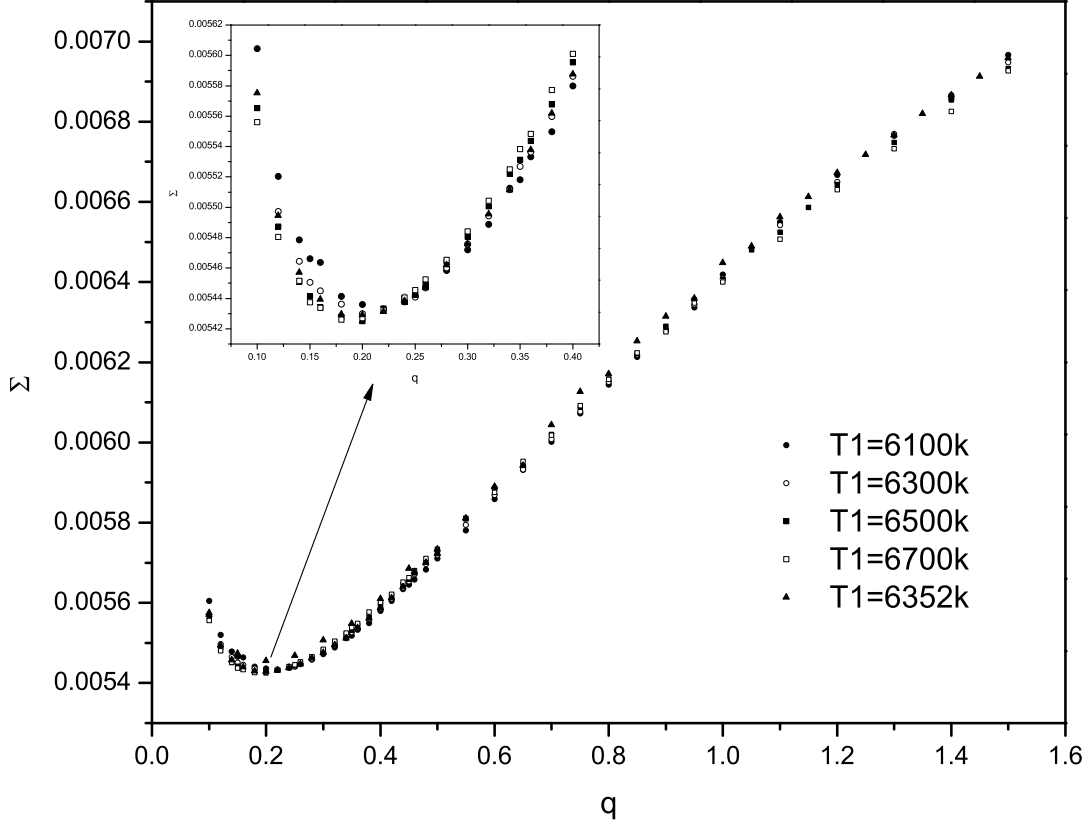


Fig. 6.— q -search diagrams of $T_1 = 6100\text{K}$ (solid circles), $T_1 = 6300\text{K}$ (open circles), $T_1 = 6500\text{K}$ (solid squares), $T_1 = 6700\text{K}$ (open squares) and $T_1 = 6352\text{K}$ (triangles)

parameter, and the results suggest that the third light contribute nearly a quarter of the total luminosity in the triple system. According to the third light values in $V R_c I_c$ filters listed in Table 4, the color index of the tertiary component are calculated to be $V - R_c = 0.39$ and $R_c - I_c = 0.24$, which corresponds to a spectral type of F5V. It means that MQ UMa has a quite massive and an early type tertiary component. In addition, the existence of the third component may probably be confirmed by spectroscopic observations in the future. As discussed by Qian et al. (2013, 2014), the existence of an additional stellar component in the binary system may play an important role for the formation and evolution by removing angular momentum from the central binary system during the early dynamical interaction or late evolution. The angular momentum and orbital period of the binary system will decrease, and the initially detached binaries can evolve into contact configuration via a case A mass

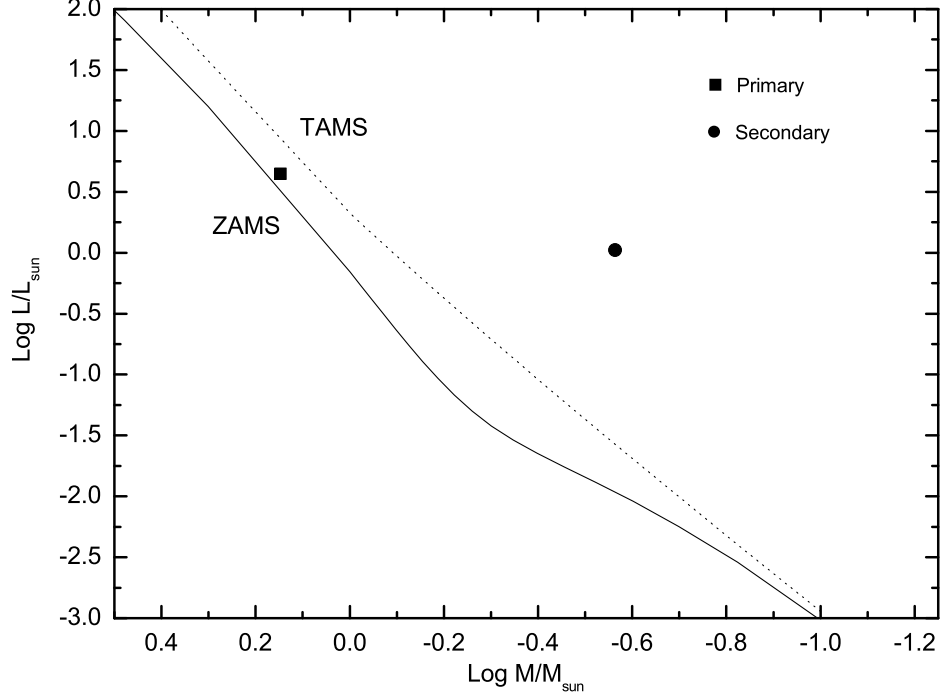


Fig. 7.— The two components of MQ UMa are plotted in the H-R diagram. Solid line represents the Age Main Sequence (ZAMS) and dash line represents the Terminal Age Main Sequence (TAMS).

transfer during their main sequence evolutionary stage.

High fill-out, low mass ratio overcontact binary systems are at the final evolutionary stage of cool short-period binaries. They may merge into a single rapid-rotation star. As a consequence, high fill-out, low mass ratio overcontact binary stars may be the progenitors of blue stragglers and FK Com type stars. A sample containing 16 high fill-out, low mass ratio overcontact binaries are presented in Table 6. Most of them are triple systems and all of them are undergoing a continuous long time period variations (decreasing or increasing). System with a decreasing period will evolve into a single rapid-rotation stars when the photospheric surface of the binary systems is close to the outer critical Roche lobe, while system with an increasing period may merge when it meets the more familiar criterion that the orbital angular momentum is less than 3 times of the total spin angular momentum (Hut 1980). As for MQ UMa, the orbital period analysis based on observations collected from public

available data and our own observations reveals that it is a triple system. However, we can not determine the exact orbital period of the third component and it is unclear whether it is undergoing a long time period variations (decreasing or increasing). Since the period variations are very important to understand their formation and evolution scenario, those binary systems listed in Table 6 together with MQ UMa will be long-time monitored in the future.

Table 6: Parameters of High Fill-Out, Low Mass Ratio Overcontact Binaries

Star name	T_1	T_2	Period	q (days)	f	i	dp/dt	Cyclic $\times 10^{-7} \text{d/y}$	Ref.
FG Hya	5900K	6012K	0.32783	0.112	85.6 %	85.25°	-1.96	yes	(1)
GR Vir	6300K	6163K	0.34698	0.122	78.6 %	83.36°	-4.32	yes	(2)
IK Per	9070K	7470K	0.67603	0.191	52.0 %	77.75°	-2.50	yes	(3)
CU Tau	5900K	5938K	0.41254	0.177	50.1 %	73.95°	-18.1	-	(4)
TV Mus	5980K	5808K	0.44586	0.166	74.3 %	77.15°	-2.16	yes	(4)
XY LMi	6144K	6093K	0.43689	0.148	74.1 %	81.04°	-1.67	-	(5)
V410 Aur	6040K	5915K	0.36635	0.143	52.4 %	78.6°	+8.22	-	(6)
XY Boo	6324K	6307K	0.37055	0.186	55.9 %	69.0°	+6.25	-	(6)
V857 Her	8300K	8513K	0.38223	0.065	83.8 %	85.43°	+2.90	-	(7)
AH Cnc	6300K	6265K	0.36044	0.168	58.5 %	90.00°	+3.99	yes	(8)
QX And	6500K	6217K	0.41217	0.233	58.9 %	56.20°	+2.48	-	(9)
EM Psc	5300K	4987K	0.34396	0.149	95.3 %	88.60°	+39.7	yes	(10)
V345 Gem	6115K	6365K	0.27477	0.142	72.9 %	73.3°	+0.59	yes	(11)
V1191 Cyg	6500K	6626K	0.31338	0.107	68.6 %	80.4°	+4.5	yes	(12)
CK Boo	6380K	6340K	0.35515	0.111	71.7 %	65.9°	+0.98	yes	(13)
DZ Psc	6210K	6195K	0.36613	0.136	89.7 %	78.97°	+7.42	yes	(14)

Reference: (1) Qian & Yang (2005); (2) Qian & Yang (2004); (3) Zhu et al. (2005); (4) Qian et al. (2005a); (5) Qian et al. (2011); (6) Yang et al. (2005); (7) Qian et al. (2005b); (8) Qian et al. (2006); (9) Qian et al. (2007); (10) Qian et al. (2008); (11) Yang et al. (2009); (12) Zhu et al. (2011); (13) Yang et al. (2012); (14) Yang et al. (2013)

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